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SEQUENTIAL SAMPLING OF BLACK HILLS BEETLE POPULATIONS

by
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INTRODUCTION

Sequential analysis is a technique for testing hypotheses. It involves a flexible sample size instead of the fixed size required in conventional sampling procedures. Goulden[1/] states: "In this method the principle of allowing the results obtained to determine the extent of sampling is carried to its logical conclusion, i.e., to the point of allowing the results obtained to determine exactly the extent of the sampling required to reach a decision." In the sequential procedure, sampling units are examined until the cumulative results fall into one or more classes distinguished by previously determined limits. Thus, the sampling may be terminated at any observation.

The least work is required where population levels are extremely low or extremely high. Sequential sampling usually saves considerable effort by preventing oversampling. Of course, practical limitations require an upper restriction on sample size.

Waters[2/] describes the development of this sampling system and the formulas for computing plans for various types of distributions. The sequential method was developed during World War II and was used for acceptance inspection in war plants. Wald[3/] and the Columbia University Statistical Research Group[4/] developed general formulas for various types of problems. Since Oakland's work[5/] numerous reports on the application of the method to biological problems have been published.

1/ Goulden, Cyril H. Methods of statistical analysis. Ed. 2, 467 pp., illus. New York. 1956.

2/ Waters, W. E. Sequential sampling in forest insect surveys. Forest Sci. 1: 68-79. 1955.

3/ Wald, A. Sequential tests of statistical hypotheses. Ann. Math. Statis. 16: 117-186. 1945.

4/ Columbia University. Sequential analysis of statistical data: applications. Columbia Univ. Statis. Res. Group Rpt. 255 (rev.) and Sci. Res. and Devlpmt. Appl. Math. Panel Rpt. 30.2R (rev.). 393 pp. Columbia Univ. Press. 1946.

5/ Oakland, G. B. An application of sequential analysis to Whitefish sampling. Biometrics 6: 59-67. 1950.

This method of sampling has been used in forest insect surveys. Biological evaluations of insect infestations must be designed to reveal information on the severity and trend of an infestation. The infestation of defoliating insects may be classified as light, medium, or heavy. The classes refer to intensities of feeding on the foliage. In evaluation of bark beetle conditions, the infestations can be classed as decreasing, static, or increasing, based on surviving populations. These classes are for use in predicting trends of the infestations.

SAMPLING THE BLACK HILLS BEETLE

A procedure for sampling Black Hills beetle (Dendroctonus ponderosae Hopk.) infestations for trend predictions, using a fixed sample size, has been developed.6/ The method requires counting the live beetles in early July in fifty 6- by 6-inch bark samples removed from the tree 5 to 7 feet above the ground. Two samples are taken from each of 25 infested trees, one from the north and one from the south side. By this procedure accurate estimates generally can be recorded. However, in some infestations 50 samples are more than necessary; in others more than 50 are needed.

The mechanics of tree selection and bark removal are the same when using sequential sampling; the procedure differs only in that when enough samples have been examined, sampling ceases. For practical purposes an upper limit of 80 samples is included in the method. An upper limit must be set because in borderline areas sampling could continue until several hundred samples are taken. After 80 samples are examined and no distinct decision is indicated, the trend is considered to be in the higher class.

A prediction of increase may be made after only one or two trees are examined. This could result in a completely incorrect prediction if trees with unusually large numbers of surviving beetles were sampled. But this is avoided by requiring that a minimum number of samples be taken.

A good sequential sampling plan cannot be developed without knowing the mathematical distribution of populations under study. Waters2/ presents formulas for computing sequential plans for four distributions including the negative binomial. Black Hills beetle population data for 6- by 6-inch bark samples have been fitted to the negative binomial distribution.6/

Sequential plans are defined by one or more pairs of parallel decision lines which serve, in this case, as criteria for distinguishing between the trend classes.

Two kinds of error are involved in predicting trends in infestations. There is the probability or risk α of rejecting a null hypothesis when it is in fact true, for example, calling a static trend decreasing; and the probability or risk β of accepting it when it is not true, such as calling a decreasing infestation static. The values assigned to these risks must be selected in a practical way. Generally, odds of 1 in 10 are acceptable for insect damage surveys with a view to applying control measures, and both α and β are set

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6/ Knight, Fred B. Measuring trends of Black Hills beetle infestations. U. S. Forest Serv. Rocky Mountain Forest and Range Expt. Sta. Res. Note 37, 6 pp., illus. 1959. [Processed.]

at 0.10. Certain other situations may require that the odds be set higher or lower than those cited above. For a situation indicated later, $\alpha = \beta = 0.20$.

The class limits used in computing the plans are based on the data obtained in population studies conducted between 1952 and 1958:

Decision 1 -- Decreasing = 4 or less beetles per 6- by 6-inch sample
Static = 5 or more beetles per 6- by 6-inch sample

Decision 2 -- Static = 8 or less beetles per 6- by 6-inch sample
Increasing = 9 or more beetles per 6- by 6-inch sample

SAMPLING PLANS

Two sampling plans have been developed -- Plan A, where $\alpha = \beta = 0.10$; Plan B, where $\alpha = \beta = 0.20$. The pooled k for decreasing, static, and increasing infestations is 1.3930. The formulas for the pooled k and the sequential plan were presented by Waters.[2/]

PLAN A

The decision lines for this plan are:

1. For decreasing vs. static infestations:

$$d_1 \leq 4.4757\,n - 41.4728$$

$$d_2 \geq 4.4757\,n + 41.4728$$

2. For static vs. increasing infestations:

$$d_1 \leq 8.4934\,n - 132.1731$$

$$d_2 \geq 8.4934\,n + 132.1731$$

The sequential plan is presented in graphic form in figure 1 and in tabular form in table 1.

PLAN B

The decision lines for this plan are:

1. For decreasing vs. static infestations:

$$d_1 \leq 4.4757\,n - 26.1651$$

$$d_2 \geq 4.4757\,n + 26.1651$$

2. For static vs. increasing infestations:

$$d_1 \leq 8.4934\,n - 83.3878$$

$$d_2 \geq 8.4934\,n + 83.3878$$

The sequential plan is presented in graphic form in figure 2 and in tabular form in table 2.

USING THE SAMPLING PLANS

To the individual who has not sampled Black Hills beetle populations, the number of samples involved might seem extreme. However, if the walking distance to the infested area is not excessive, 80 samples is not a difficult 1-day sampling job for two men. This, of course, involves finding 40 trees and

Table 1.--Sequential table for sampling Black Hills beetle populations on 6- by 6-inch bark samples
Plan A ($\alpha = \beta = 0.10$)

Number of samples examined	Cumulative number of beetles			Number of samples examined	Cumulative number of beetles		
	Decreasing	Static	Increasing		Decreasing	Static	Increasing
20	48		302	50	182	265 to 292	557
22	57		319	52	191	274 to 309	574
24	66		336	54	200	283 to 326	591
26	75		353	56	209	292 to 343	608
28	84		370	58	218	301 to 360	625
30	93		387	60	227	310 to 377	642
32	102		404	62	236	319 to 394	659
34	111		421	64	245	328 to 411	676
36	120		438	66	254	337 to 428	693
38	129		455	68	263	346 to 445	710
40	138		472	70	272	355 to 462	727
42	147		489	72	281	364 to 479	744
44	155	238 to 242	506	74	290	373 to 496	761
46	164	247 to 258	523	76	299	382 to 513	778
48	173	256 to 275	540	78	308	391 to 530	795
				80	317	400 to 547	812

Table 2.--Sequential table for sampling Black Hills beetle populations on 6- by 6-inch bark samples
Plan B ($\alpha = \beta = 0.20$)

Number of samples examined	Cumulative number of beetles			Number of samples examined	Cumulative number of beetles		
	Decreasing	Static	Increasing		Decreasing	Static	Increasing
10	19		168	32	117	169 to 188	355
12	28		185	34	126	178 to 205	372
14	36		202	36	135	187 to 222	389
16	45		219	38	144	196 to 239	406
18	54		236	40	153	205 to 256	423
20	63		253	42	162	214 to 273	440
22	72		270	44	171	223 to 290	457
24	81		287	46	180	232 to 307	474
26	90		304	48	189	241 to 324	491
28	99	151 to 154	321	50	198	250 to 341	508
30	108	160 to 171	338				

taking two samples from each. Sampling must be done in early July before the beetle flight commences. The trees are easy to find at that time because the foliage on all infested trees is discolored (fig. 3). Usually the job will require fewer than 80 samples, consequently the work will be less. Most decreasing and increasing infestations will require less than 80 samples. Static or borderline infestations may require a complete 80-sample job.

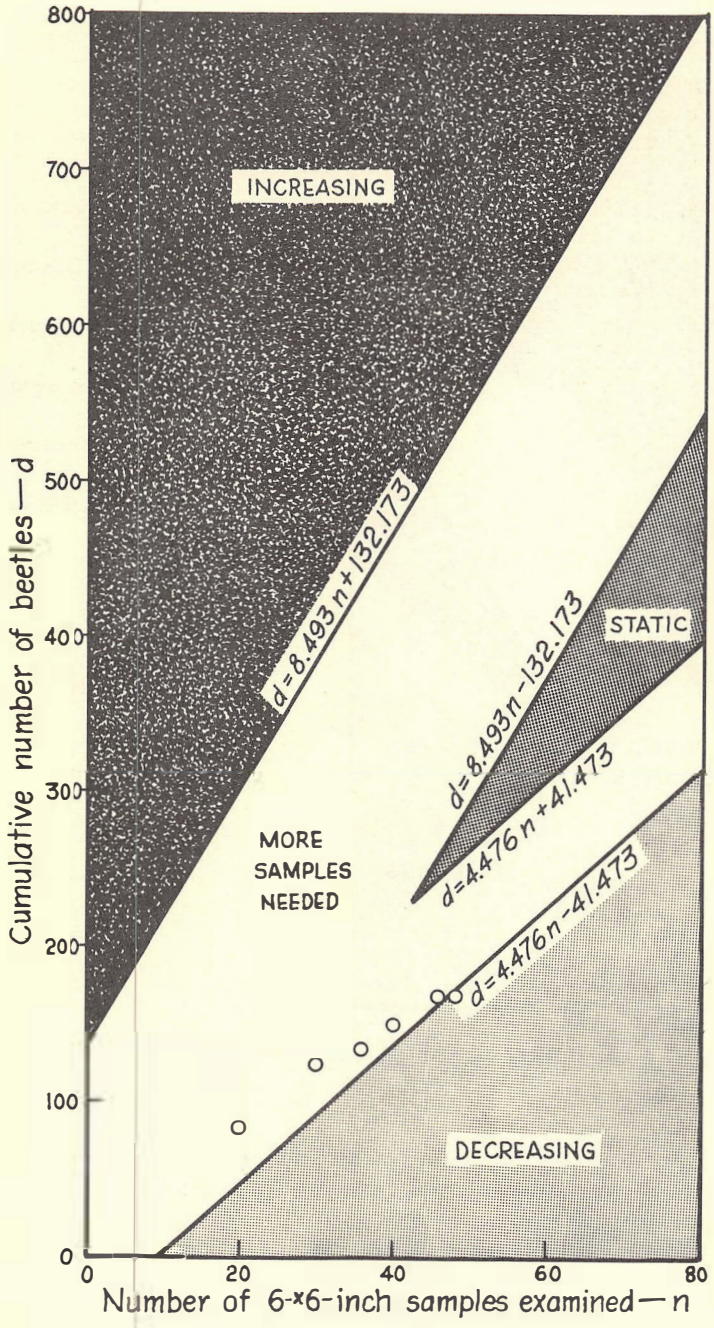

Figure 1.--Sequential graph for sampling Black Hills beetle populations in 6- by 6-inch bark samples (90 percent confidence level). The small o's represent cumulative counts in a hypothetical sampling situation. The 48th sample is below the decision line for decreasing; the infestation prediction is decreasing.

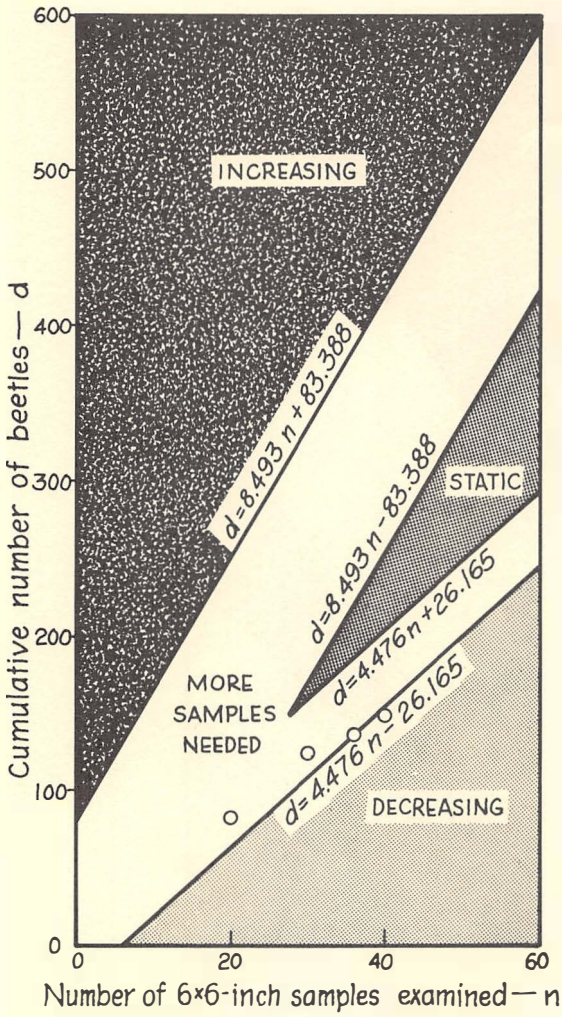

Figure 2.--Sequential graph for sampling Black Hills beetle populations in 6- by 6-inch bark samples (80 percent confidence level). By the use of the same hypothetical situation as in fig. 1, the decision can be made after recording 36 sample counts.

For example, let us suppose that a crew of two men enters an infested area on July 9. They commence sampling infested trees, making a cumulative total of insects as they proceed. After sampling 10 trees (20 sample units), they check Plan A (see hypothetical plot on figure 1). Their cumulative total after 20 samples is 85 live beetles; thus, they continue sampling, checking table 1 after adding each sample unit count. At 40 sample units they have a total of 150 beetles, which is very close to the decreasing trend column. When sample 48 is added the total crosses the line because their total (172) is lower than the column total (173). The infestation is classed as decreasing.

However, if, after sampling 80 units, no decision can be made, the infestation is classed in the higher of the two classes involved. For example, if the cumulative counts are between decreasing and static, the infestation is classed as static. Borderline cases should always be considered in the higher classification.

Figure 3.--
Black Hills
beetle-infested
trees as they
appear in July
before beetle
emergence.

Sequential sampling Plan A was used in a comparison with data from two infested areas in 1959. In one situation a cumulative total of 358 beetles was recorded after removing 58 samples. In the other a total of 329 beetles was obtained after removing 64 samples. Thus, in both cases a static condition was indicated. The same predictions were made by the fixed sampling procedure. These two infestations required more sampling than by the fixed sampling method. This is to be expected when static situations are involved. Sampling will be less for rapidly decreasing or increasing infestations.

Plan B is a special table designed for use in certain areas where a higher risk of error can be or must be accepted. In some situations very few trees are being killed by beetles but evaluations are necessary to determine the current status of the insect populations. The infested trees may be extremely scattered in the infestations and 80 sample units may be impossible to find and

sample in the time available. The number of trees killed would remain low and a control project would be unlikely even if an increasing infestation were expected. These factors would make it possible to accept a higher risk of error. Plan B should be used only when necessary. When the added risk is considered thoughtfully, Plan B will not be used excessively.

Other situations might require an evaluation with less risk than in Plan A. Additional plans can be computed from the k values in this paper and the formulas by Waters. A large control project might present a situation requiring an evaluation with a lower risk of error. A "mop-up" project would be necessary the following year except where the populations emerging from missed trees is very low, i.e., indicative of a decreasing infestation. These missed trees would be impossible to locate. The evaluator could select and reserve trees that would not be treated during the project. These could be treated by the sampling crew if the project were completed before the sampling date (fig. 4).

Figure 4.--Treating study trees after beetle populations have been sampled, July 1958.

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